Research Note

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SLASH BURNS WELL AT B.I. 10 to 20

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Fire danger measurements have been used for the past ten years in Region One as guides to judgment of the number of men needed in the fire control organization. Little if any use has been made of these same measurements, however, as indicators of good and bad slash burning conditions. There is an opportunity here which should be especially useful during the present period of excessive slash accumulations with inexperienced and insufficient manpower to do the burning. Results of some recent tests are also significant as they show the effects to be expected according to Burning Indices, or B.I.'s, given by the new Burning Index Meter.

On October 11 and 12, 1944, on the Priest River Experimental Forest several piles of white pine slash, two to four years old, were burned in three different fuel conditions, (1) on deep duff, (2) in scattered twigs, and (3) surrounded by cured grass, ferns, and other light vegetation. Piles were ignited throughout the day and early evening. Combustion was complete except for isolated branch stubs projecting outside the perimeter of the pile. Not a single case required any trenching or work to prevent spread of the fire to other piles or through other fuels. There was no spread, no spotting, and no hang-overs in either deep duff or rotten logs.

As these piles were all in or near a small stream bottom about 100 yards wide or on the lower portion of a south-facing aspect, the relation of fire behavior to Burning Index (at a standard, fully exposed danger station less than a mile away) is believed to be representative of what may be expected elsewhere on all but the most exposed and driest sites.

Fire danger data on these two days were as follows:

Date	Maximum temperature Degrees	Minimum humidity Percent	Afternoon wind m.p.h.	Fuel moisture Percent	B.I. Class
October 11	77	31	3	9.3	16
" 12	72	35	3	11.1	10

Experienced brush burners will recognize the fact that the above data do not tell the whole story. While they indicate light fuel or surface conditions, they do not necessarily show the condition of deep duff or of

windfalls and other logs on the ground. These conditions are obviously important controls of whether slash fires will creep or hang over to flare up later.

At the Priest River branch station one index is obtainable from the "Large Log Moistures" measured every ten days. On October 6, less than a mile from the spot where the slash piles were burned, logs lying on the ground had the following moisture contents:

	Diameter of logs: 6"	12"	18"
	Moisture content Percent		
At an open, fully exposed site	30	25	24
Under a dense timber canopy	36	26	26

As yet we have no practicable method of measuring large log moistures at numerous field stations. It can be done electrically at selected spots in a log, but several years of testing have revealed too much error in this method. It is being done at Priest River by weighing logs 5 feet long, but this requires a difficult procedure in determining the oven-dry weight, special scales, and a wrestling match with the 200-pound, 18-inch logs every ten days without losing a splinter from a log in the process. Furthermore, at least three logs of each size are essential to get a dependable average. Consequently the large log moistures given above are merely evidence of information being acquired which will not become useful until we can devise a practicable field method.

In the meantime, the old rule of thumb of white pine slash burners, that brush burning should wait until fall rains amount to 2 inches, is the best available criterion of the condition of deep duff and large logs. The tests this year verify that criterion because the test fires did not creep or hang over, and the fall rains (September 1 to October 10) had amounted to 2.37 inches.

By combining the Burning Index with this rule of thumb, it is evident that fall burning of white pine slash can be planned with safety and efficiency at any time after approximately 2 inches of rain have fallen and when the B.I. rating is between 10 and 20. The latter is significant, of course, because with higher winds, lower humidity, or both, slash fires might give trouble. But in such cases the B.I. would rise and show this danger, provided that the measurements of factors used in computing the B.I. were made at a site comparable to the site of the slash burning. Where these two sites differ the factor measurements at the danger station can be readily converted to represent the slash burning site by use of charts 7, 9, and 13 in U.S.D.A. Circular No. 591, "Influence of Altitude and Aspect on Daily Variations in Factors of Forest Fire Danger."

A complete method of supervision and control is therefore available. The dangers and costs of slash disposal warrant its use.

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Where and When to Measure Forest-Fire Danger

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This article presents the results of a study to determine the place, time, and number of measurements that should be made to obtain dependable ratings of "average-bad" fire conditions without an excessive number of stations or observations. The author concludes that under the conditions prevailing in the Priest River Experimental Forest in northern Idaho a single measurement taken daily at noon at either a valley-bottom or a south-slope station is adequate for the rating of fire danger.

FOREST-fire danger[2] is now measured in every forest region of the United States. Several systems of measuring and evaluating danger have been devel̀oped (*3*), all of which are of value in the current supervision of fire suppression and in fire-control planning.

Studies at the Northern Rocky Mountain Forest and Range Experiment Station have aimed consistently to determine (1) what factors affect fire danger, (2) how they may be measured, (3) where they should be measured, (4) when they should be measured, and (5) how to integrate these measurements into a reliable, practical, and readily usable scale. These distinct components of the problem constitute the "what, how, where, and when" of fire danger. The "why" of fire-danger measurement is primarily to indicate the size of the control organization needed to cope with existing fire danger.

Present policies require that preparations be made for controlling all fires that start under "average bad" or easier conditions. This means a fire-control organization capable of suppressing all fires, *except those that might start in the worst fuels under the very worst burning conditions,* and recognizes the importance of the law of diminishing returns in fire-control planning. Hornby (*7*) accepted the fact that beyond a certain point it is more economical to take the loss than it is to bear the cost of preventing that loss. Recently Knorr (*8*) recognized the application of the average-bad principle in selecting the locations of fire-danger stations to be used as a guide in manning for fire control in the longleaf pine type.

It was early recognized that the same principle that governs fire-suppression practices should also govern the place and time of making danger measurements. Fire danger is known to vary greatly from place to place and from time to time at the same place. For example, in the same fuel type the danger is obviously greater on south than on north slopes, at lower than at higher elevations, and during the mid-afternoon than at night. Therefore, if an area is "manned" to cope with the average fire danger of all the aspects, elevations, and hours, the organization should be able to handle with ease all fires on the less-dangerous-than-average north slope, especially those occurring at night; but it would be entirely inadequate to control fires starting on the more-dangerous-than-average south slope, particularly during the critical afternoon period. These important considerations were not adequately taken into account in the statistical analyses of fire-weather station distribution made by Morris (*11*).

In the early stage of measuring fire danger in the Northern Rocky Mountain Region, the availability of men at an established station and convenience in making the measurements were the controlling criteria as to where and when the average-bad should be measured. These are still dominant factors in actual practice. By 1934, however, progress in other phases of evaluating fire danger had shown the need for a better basis. Therefore, very appropriately at that time, a study was started at the Priest River Experimental Forest to find out more precisely how the various fire-danger factors differed in mountainous terrain in order to acquire more complete and basic knowledge of where and when to measure fire danger.

The results of that altitude and aspect study have been given in two previously published

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[2]"Forest-fire danger" is used in its broad sense as defined in the *Glossary of Terms Used in Forest Fire Control,* U. S. Department of Agriculture, Forest Service, 1939, namely, "A general term expressing the sum total of both the constant and variable factors which determine whether fires will start, spread, and do damage, and which determine their difficulty of control."

reports (*5, 6*). This paper will show, in so far as wind and the atmospheric factors affecting fuel-moisture conditions are concerned, how the average-bad fire condition in rugged topography may be evaluated and where and when it can be measured.

Burning Indexes[3] as a Measure of Average-Bad Fire Danger

Fire-weather data were obtained at seven fully exposed stations. One of these, which might be called the valley-bottom control because of its similarity to a danger station at any ranger station, was located in a flat valley bottom at 2,300 feet elevation. The remaining six were established in pairs located on true north and south slopes at elevations of 2,700, 3,800, and 5,500 feet on a ridge rising from east to west. All pairs were within 100 feet elevation of the ridge crest. At each station wind velocity at 7½ feet above the ground and moisture content of duff and half-inch fuel moisture indicator sticks were measured and recorded continuously by an anemohygrograph.

The fuel moisture and wind velocity data of each station were integrated by the Northern Rocky Mountain fire danger meter (model 5) into burning indexes on a scale of seven classes. These embrace the entire range of burning conditions, from no spread of fire under Class 1 to spreads of 1,500 to 2,000 acres per hour when the explosive conditions under Class 7 prevail.

Figure 1 shows the altitudinal distribution of the burning indexes on both north and south slopes for 24 hours of the median day[4] in July-August, 1938. The conditions shown are typical or normal for the clear, dry fire weather that is so characteristic of northern Idaho summers. Median values are used, since mean values or arithmetic averages are too much affected by the occasional, unusual stormy weather (*1, 4, 7*) to be typical of the summer climate of this region with its high temperatures, low relative humidity, scanty rainfall, and long periods of drought.

[3]The Committee on Forestry Terminology of the Society of American Foresters has defined burning index as "a relative number denoting the combined evaluation of the inflammability of forest fuels and the rate of spread of fire in such fuels for specific combinations of fuel-moisture content, herbaceous stage, and wind velocity." In some former publications (*5, 6*), burning indexes have been termed "fire-behavior classes."

[4]Median day is the day on which conditions were such that half of the July-August days showed worse fire danger and the other half less fire danger.

Figure 1 may be likened in some respects to a contour map save that its "contours" are lines of equal burning index rather than lines of equal elevation. At 6 a. m., for example, there are "valleys" of low burning indexes at both low and high elevations with "ridges" of high burning index between. These culminate in the highest "peak" around 2 p. m.

The data are readily usable to approximate the burning index at any elevation on north and south slopes between 2,200 and 5,500 feet and at any hour of the day or night. For example, the figures on the vertical line for 6 a. m. in Part A show that the burning index increases from valley bottom up to 3,500 feet and then decreases toward the mountain top, as follows:

Elevation, feet	Burning index, class
2,400	2.6
3,000	3.2+
3,500	3.5
4,000	3.4—
4,500	3.3+
5,000	3.2
5,500	3.1

Similarly, the horizontal line for 3,000 feet elevation on this same slope shows that the burning-index ratings for various hours of the day were as follows:

Hour of day	Burning index, class
10 p. m.	3.8
2 a. m.	3.4
6 a. m.	3.2+
10 a. m.	4.4
2 p. m.	5.2—
6 p. m.	4.6

If average-bad fire danger is concretely defined in terms capable of numerical expression (*10*), the information in Figure 1 obviously can be used to determine when and where to measure "average-bad" with respect to aspect, elevation, and time. The chart clearly shows that at identical hours and elevations, higher burning indexes exist on the southerly aspect (A) than on the northerly aspect (B). Likewise, at all elevations on the southerly aspect the danger is greater between 10 a. m. and 6 p. m., the so-called burning period, than at any other hour of the entire day. These facts lead to one logical conclusion: the measure of the average-bad must be based upon the average of fire-danger conditions as represented by the burning indexes which prevail on the southerly aspect and valley bottom between the hours of 10 a. m. and 6 p. m.

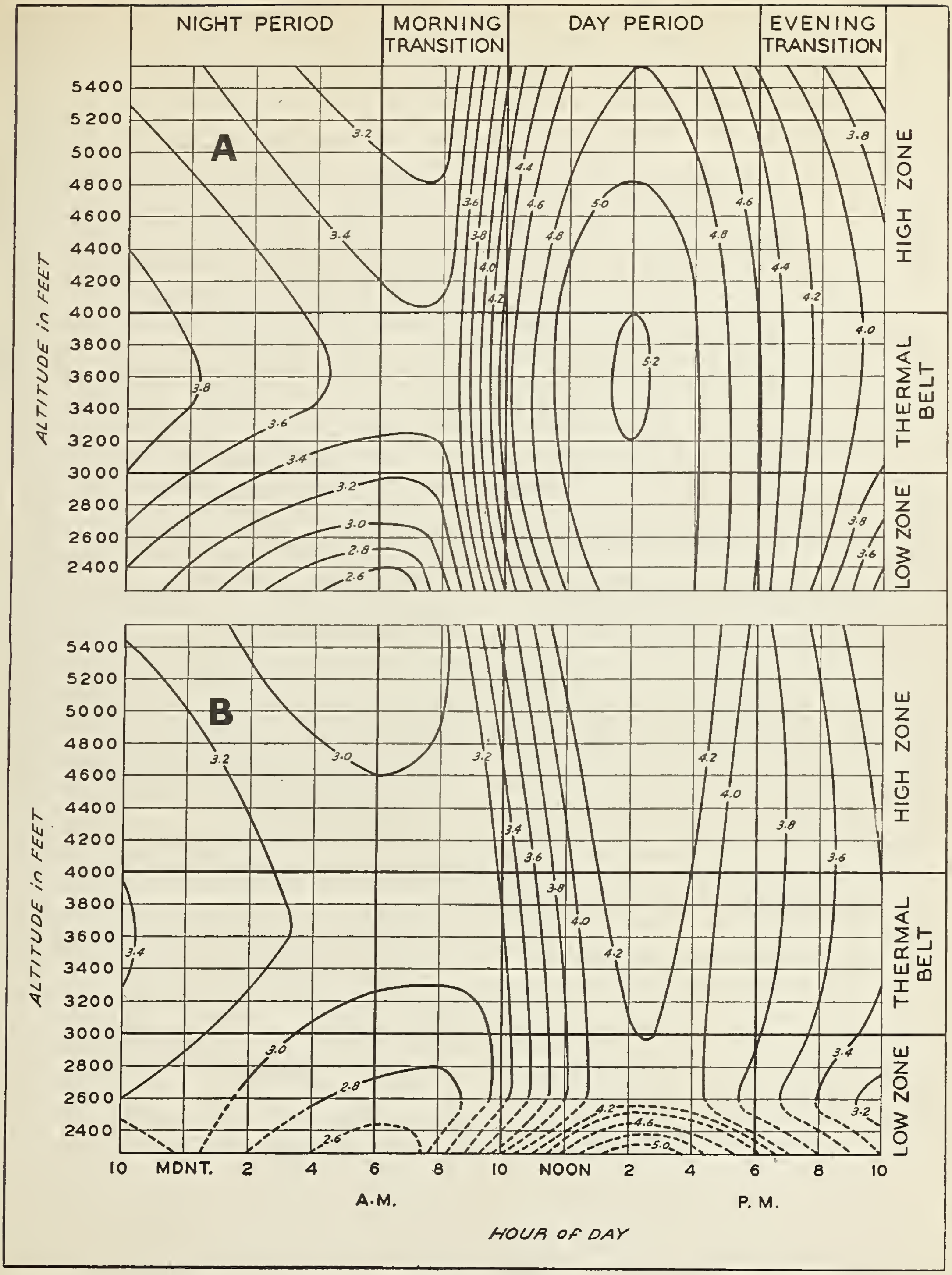

Fig. 1.—Burning-index ratings for different altitudes, different hours of the day and night, and on south (Part A) and north (Part B) slopes for the median day of July-August, 1938, on the Priest River Experimental Forest. The isograms, or "contour lines," are lines of equal burning index.

On the median day of July-August, 1938, the burning index of the average-bad condition was class 4.8. This was obtained as follows: (1) For the two months the average burning index of the critical period (10 a. m. to 6 p. m.) was calculated separately for each of the three south-slope and the one valley-bottom stations. (2) Next, the percentage of all flats and south slopes included in the study area (6,000 acres) which fell within the altitudinal zone best represented by one of each of the four stations was estimated from a topographic map. (3) The average burning index of each station obtained in step 1 was then multiplied by the appropriate percentage from step 2 and the four products were added together. (4) Their sum, class 4.8, was the weighted-average burning index of all south slopes and valley-bottom areas embraced by the study.

Figure 1 (A) shows that on the normal day, between 10 a. m. and 6 p. m., a burning index of class 4.8 occurred twice in the valley bottom and at all elevations on the south slope except at the highest point, where it prevailed only once at 2 p. m. Consequently, the average-bad condition, as defined, could be measured at any place in the valley bottom or on the south slope. In the valley bottom these measurements could be made either at noon or 5 p. m. Measurements at any other hours would give indexes either definitely below or above "average bad" for the area. On the south slope, similar measurements would have to be made at 3,000 and 4,000 feet around 11 a. m. or 5 p. m., and at 5,500 feet around 2 p. m.

Some Practical Considerations

As brought out above, the average-bad can be measured at more than one place, and at different hours of the day in some places. Usually men for this purpose are readily available only at valley-bottom ranger stations or mountain-top lookout points. The valley-bottom and 5,500-foot south-slope stations used in this study were typical of such localities. Measurements of average-bad made at these stations were tested to answer several important practical questions. (1) How accurately do single ratings at an individual station represent the average-bad from day to day; (2) for the stations in question, which of the three ratings approximated average-bad most accurately; and (3) how much can the accuracy of daily ratings be increased by averaging several measurements at an individual station or combining several values from different stations?

Accuracy of Individual Station Ratings

Table 1 shows the accuracy with which the average-bad burning index on any July-August day was approximated by single daily ratings at either the valley-bottom or the mountain-top station. Any of the three single measurements rated average-bad with an accuracy sufficient for practical purposes, but the one at 2 p. m. on the south slope near the lookout station was best. While the practice of measuring only once each day and then only at a lookout station would be readily feasible on most Forest Service ranger districts in July and August, it would not serve during earlier and later months when the lookout stations are often unoccupied.

Relative Accuracy of the Three Sets of Data

As shown in Table 1, the 2 p. m. burning indexes from the south-slope station at 5,500-foot elevation were most accurate. There on 50 per cent of all days tested, the ratings differed from the average-bad burning index by only ± 0.1 class or less; on 66 per cent of the days the difference was ± 0.24 class or less. However, at the valley-bottom station the readings were almost as reliable. There the noon data varied from the average-bad rating by ± 0.15 class or less on half the days, and by ± 0.34 class or less on two-thirds of the days. Furthermore than 5 p. m. data at this same station deviated from average-bad by not over $\pm .20$ and ± 0.33 classes on half and two-thirds of the days, respectively.

The largest overestimate exceeded the average-bad rating by 1.3 classes and the largest underestimate was 1.0 class too low. These errors might appear to be of practical importance, but they all occurred on days when the average-bad burning index was low. On such days, when fire will not give serious trouble, errors of this amount are not of such significance as when danger is high and success in efficient fire control depends vitally on accurate estimation of conditions.

The maximum overestimate of 1.3 classes occurred, for example, on July 6 when average-bad for the 6,000-acre area as a whole was rated at a burning class of 2.4. At noon on that day, mea-

surements at the valley-bottom station indicated the burning index at class 3.8. However, because of rain which started at 2 p. m. the same day, the 5 p. m. index at this station fell to class 1.6 or 0.9 class below the average-bad. Similarly, the diurnal trend was abnormal on the day immediately following owing to rapid drying of unusually wet fuels. Only on days which were affected by recent rain did errors exceeding ±0.5 class occur. No error exceeding that amount occurred on any day unaffected by rain which rated class 3.6 (moderately bad) or more. In fact, on the moderately dangerous days the ratings were generally accurate within ±0.3 class and less.

Increasing the Accuracy of Ratings

While such accuracy is reasonably good, analysis shows that averages of two or more measurements from a single station or from separate stations give greater accuracy than any individual measurement. Three different combinations of two daily estimates and one additional combination of all daily measurements were tested.

As is evident from Table 2, averages of three daily measurements, two in the valley bottom and one on the mountain top, approximated average-bad with remarkable dependability. The median and standard errors of such an estimate were reduced to the inconsequentially low points of about one-tenth of a class. Even its largest single error, an overestimate of 0.4 class, would not be of serious importance to a protective organization. Two measurements in the valley bottom and one on the mountain top each day therefore can be used, if justifiable on other bases, to give maximum accuracy.

Discussion

The above analyses indicate that theoretically the average-bad burning index can be best approximated from combinations of three daily measurements at two stations. From the practical point of view, however, can any fire-control organization really make use of ratings as refined as this? To state the question from another angle: Will the additional cost of making more than one daily measurement be justified by the financial benefits derived from the most accurate but also the most costly estimate based on three measurements?

Such questions must be answered negatively for the Northern Rocky Mountain Region when consideration is given to our knowledge of fire behavior, the uniformity of danger from day to day, and the degree of refinement employed in present-day fire-control work. Analysis indicates that on the two-thirds of the days that a fire-control organization would have been most vitally concerned with the fluctuating danger,

Table 1.—Accuracy with Which the Average-Bad Burning Index was Approximated by Single, Daily Measurements at Different Stations, July-August, 1938

Station and hour	Median error of estimate[1]	Standard error of estimate	Greatest over-estimate	Greatest under-estimate
	Class	*Class*	*Class*	*Class*
Valley bottom, 2,300 feet				
12:00 m.	±0.15	±0.34	+1.3	—0.9
5:00 p.m.	±0.20	±0.33	+0.9	—1.0
South slope, 5,500 feet				
2:00 p.m.	±0.10	±0.24	+0.6	—0.6

[1]The median difference between the measured and the estimated average-bad burning index.

Table 2.—Accuracy with Which the Average-Bad Burning Index was Approximated by Combining the Daily Measurements of Two and Three Stations, July-August, 1938

Station and hours	Median error of estimate	Standard error of estimate	Greatest over-estimate	Greatest under-estimate
	Class	*Class*	*Class*	*Class*
Valley bottom at 12 m. and 5 p.m.	±0.10	±0.19	+0.8	—0.4
Valley bottom at 12 m. and south slope, 5,500 feet, at 2 p.m.	±0.08	±0.18	+1.0	—0.4
Valley bottom at 5 p.m. and south slope, 5,500 feet, at 2 p.m.	±0.09	±0.16	+0.3	—0.7
Valley bottom at 12 m. and 5 p.m., and south slope, 5,500 feet, at 2 p.m.	±0.06	±0.11	+0.4	—0.2

single measurements estimated the average-bad from only ±0.05 to ±0.18 class less accurately than did two observations, and only ±0.13 to ±0.23 class less precisely than the median of three measurements. No fire control force in this region is at present so flexible that it can be varied for a change of only 0.23 class in fire danger.

Moreover, the variations in fire behavior within the different burning-index classes have not yet been determined to a degree that economically justifies increasing or decreasing a fire-control force to meet a change of ±0.34 class, the largest standard error for estimates based upon single daily measurements. Until fire control action can be refined to the point of actually making changes in the control forces with variations of one-third class of fire danger, one daily measurement is therefore recommended as adequate on any unit similar to the one studied.

These tests are strictly applicable, of course, only to the sampling of average-bad as here defined and computed. There is no reason, however, if some other index were wanted, why it could not be approximated by similar methods and with similar accuracy. Average-bad danger on forest areas larger than 6,000 acres could not be determined so accurately perhaps; but an accuracy within practical limitations should be obtainable during settled weather on an area many times larger than 6,000 acres providing it is climatically uniform.

Burning-index measurements, in addition to their value for rating danger on an area as a whole, also can be used by fire dispatchers to estimate burning conditions at any spot on their unit where a new fire occurs. The manner in which this may be done can be illustrated by using the values in Figure 1 to show the relationship between the danger actually measured and the danger estimated to be existing "at the fire."

Let it be assumed that two fires are reported on a day when the noon burning index of the valley-bottom station was measured and found to be class 5.2, or 0.3 class above the index shown by Figure 1 for such a station and hour. Further, assume the first fire as occurring at 3 p. m. on a south slope at 3,800 feet and the second at 8 p. m. on a north slope at 2,600 feet. According to Figure 1 (A) the aspect-elevation combination for the first fire gives a rating of about class 5.1. But this chart shows only what can be expected if the valley-bottom condition was rated as 4.8 at noon. As the valley bottom rating was actually 5.2 at noon on the day of this fire, the difference, or 0.3 class, must be added to the 5.1 shown for the fire location. The estimated burning index at the site of the first fire was therefore 5.1 plus 0.3 or class 5.4.

Similarly the danger at the site of the second fire as estimated from Figure 1 and corrected by the noon measurement was class 4.0 (class 5.2 of valley-bottom station at noon minus class 1.2, the normal difference between ratings of the valley-bottom station at noon and of a spot on the north slope at 2,600 feet elevation at 8 p. m.). The local ranger thereby is able to judge and to report probable fire behavior at these two fires far more dependably and specifically than would otherwise be possible. The action he takes for a 5.1 condition obviously will be both stronger and faster than for the class 4.0, even though the latter represents a spot at lower elevation, hence with more area above it and exposed to burning. While these are conditions and actions readily apparent to the experienced forest officer, they are not so obvious and are often overlooked by the new man to whom all fires may look equally sinister.

The several possibilities of making daily measurements were analyzed also to determine which would be the best basis for dispatchers' estimates of this kind. Each combination of station measurements was used in turn with values shown in Figure 1 to estimate burning indexes at three different sites and widely different hours. Furthermore, additional charts were constructed similar to Figure 1 but with each representing a certain limited range of danger at noon at the valley-bottom station. In using Figure 1 for this test, the estimates were confined to those days that rated 4.3 to 5.3 at the valley-bottom station. Other charts should be used for lower and higher dangers. This limited the number of estimates in each group to 30. Table 3 shows the dependability found for any one of three different measurements when used as a basis for estimating conditions on any July-August day at three other spots within the area.

In seven of the nine cases the estimated burning indexes differed from the actual by only ±0.2 class or less, on half of all the days tested. In the other cases the differences were even smaller, from ±0.1 to ±0.15 class or less. This uniformity of the median errors of estimate shows that on at least 50 per cent of the July-

TABLE 3.—ACCURACY WITH WHICH THE BURNING INDEX AT THREE DIFFERENT PLACES AND HOURS WAS ESTIMATED FROM MEASUREMENTS TAKEN AT THE VALLEY-BOTTOM STATION AT NOON AND AT 5 P.M., AND AT THE SOUTH-SLOPE STATION 5,500 FEET ELEVATION AT 2 P.M.

Situation and hour of measurement	Situation and hour of estimate	Median error of estimate	Standard error of estimate	Greatest over-estimate	Greatest under-estimate
Valley bottom, noon	South, 3,800 feet, 2 p.m.	±0.15	±0.27	+0.7	—0.4
	North, 2,700 feet, 8 p.m.	±0.2	±0.25	+0.7	—0.3
	South, 5,500 feet, 10 a.m.	±0.2	±0.40	+1.3	—0.7
Valley bottom, 5 p.m.	South, 3,800 feet, 2 p.m.	±0.2	±0.41	+0.7	—0.7
	North, 2,700 feet, 8 p.m.	±0.1	±0.22	+0.6	—0.5
	South, 5,500 feet, 10 a.m.	±0.2	±0.39	+0.8	—0.9
South slope, 5,500 feet, 2 p.m.	South, 3,800 feet, 2 p.m.	±0.2	±0.22	+0.4	—0.6
	North, 2,700 feet, 8 p.m.	±0.2	±0.40	+0.6	—1.3
	South, 5,500 feet, 10 a.m.	±0.2	±0.35	+1.0	—0.9

August days concerned, the distribution of burning indexes was so similar to that shown by Figure 1 that it mattered little where or when the measurements were made. For example, on half the days the burning indexes at 2 p. m. on the south slope at 3,800 feet elevation were estimated just as accurately from measurements made 21 hours earlier and 1,500 feet below (valley station at 5 p. m.) as from observations taken at the same time and 1,700 feet higher (south-slope station 5,500 feet at 2 p. m.) In each case the median error was the same, ±0.2 class.

The standard errors in Table 3 show, however, that on days when the distribution of fire danger was not so typical, greater accuracy was obtained when the measured and estimated burning indexes were made near each other with respect to both place and time. Thus, the standard error for estimates of 2 p. m. burning indexes at 3,800 feet on the south slope was only ±0.22 class when based upon measurements made at the 5,500-foot south-slope station at 2 p. m. It was ±0.41 class when using 5 p. m. measurements of the valley-bottom station.

Large overestimates and underestimates in excess of ±0.5 class occurred occasionally at all of the stations tested (Table 3). Errors of that magnitude are probably less important in the present instance than they would be in rating general fire danger. In actual dispatching they would be largely avoided. No dispatcher, for example, would accept or use without modification an estimate of the burning index following a rain which was based upon measurements that were taken before that rain started. Yet four of the largest overestimates in Table 3 were caused by exactly such a combination of conditions. Similarly, when the typical topographic distribution of fire danger is disturbed by uneven distribution of rain, by unusual changes in wind velocity and direction, or by cloudiness, then the estimates of burning index should and must be modified by common-sense allowances based upon experienced judgment. Good dispatching will always demand the exercise of sound judgment. This can be guided, but never replaced, by mechanical methods of estimating.

For use in dispatching, burning indexes should therefore be measured as near as practical to bad fire zones and preferably just prior to the time of day when fires usually occur. In this connection, noon measurements should be more valuable than those made at 2 p. m.; the latter in turn should have greater value than 5 p. m. data. Both for use by the fire dispatcher and in over-all fire-danger rating, measurements should not be made during those before-noon hours when the burning index is changing rapidly, i.e., in valley bottoms from 7 through 11 a. m., and at mid-elevations on south slopes from 8 through 10 a. m. Measurements made at such times are not so reliably indicative of what conditions will be elsewhere on the area as are measurements made after the burning index has come to its daily comparative equilibrium.

SUMMARY

Fire-danger ratings are necessary to sound fire-control planning. Among other uses, they furnish a very practical index of the presuppression manpower needed on an area. Danger measurements made at one spot and used to rate the fire danger of the immediately surrounding area must be representative of the more dangerous portions of the area and of the more critical hours of the day, but not the most dangerous exposures at the very peak of the day. This average-bad condition can be sampled and expressed numerically through burning indexes obtained by integrating measurements of fuel

moisture and wind velocity. For the area included within the 6,000-acre Priest River Experimental Forest, it was found that these measurements could be made either in the valley bottom at noon or 5 p. m., and on south slopes, depending upon elevation, at 11 a. m., 2 p. m., or 5 p. m.

Single daily measurements made at a valley-bottom station at noon or 5 p. m., and at a 5,500-foot south-slope station at 2 p. m., represented the average-bad burning indexes for the area as a whole with an accuracy well within the limits of the practical application of fire-danger ratings. A combination of two daily measurements gave more representative burning-index values than did single observations, while three daily measurements improved the accuracy of average-bad ratings still further. Few, if any, fire-control organizations are, however, sufficiently flexible to use effectively burning indexes more precise than those obtained from single daily measurements. Nor is present-day knowledge of fire behavior so complete that minute differences in estimated fire danger have practical implications. Hence, there is no economic justification for financing additional measurements in order to obtain relatively meager further refinement.

For dispatching purposes it matters little on normal or average July-August days in the Northern Rocky Mountain Region where or when the burning index is measured. Each of three sets of data taken at different sites and hours of the day provided almost equally precise estimates of the burning index at other places and hours. On less typical days such as when rain occurred, however, better estimates were obtained when measured and estimated burning indexes were made near each other with respect to both place and time. Under these conditions the need of the fire dispatcher would be best served when measurements are made close to high-danger areas and near the beginning of the daily critical period. From the dispatcher's point of view, the noon measurement is the best of the three time periods tested and the 2 p. m. measurement is next best.

Literature Cited

1. Gisborne, H. T. 1935. When a normal is not a normal. Amer. Met. Soc. Bul. 16: 171-175.
2. ————. 1939. Hornby's principles of fire-control planning. Jour. Forestry 37: 292-296.
3. ————. 1939. Forest pyrology. Sci. Monthly 49(7): 21-30, illus.
4. Hayes, G. Lloyd. 1935. Don't let a "normal" deceive you. U. S. Forest Serv. Bul. 19:4.
5. ————. 1941. Influence of altitude and aspect on daily variations in factors of forest-fire danger. U. S. Dept. Agric. Cir. 591. 38 pp., illus.
6. ————. 1942. Differences in fire danger with altitude, aspect, and time of day. Jour. Forestry 40:318-323, illus.
7. Hornby, L. G. 1936. Fire control planning in the Northern Rocky Mountain region. North. Rocky Mountain Forest and Range Expt. Sta. (Multi.).
8. Knorr, Phillip. 1942. Variations in fire-danger factors on a ranger district in the longleaf pine region. Jour. Forestry 40: 689-692.
9. Mindling, George W. 1940. Do climatological normals serve adequately as normals? Amer. Met. Soc. Bul. 21:3-6.
10. Morris, William G. 1939. What is "average bad?" Fire Control Notes 3(3):25-26.
11. ————. 1940. Statistical analysis of forest-fire weather station distribution. Jour. Forestry 38:318-321.

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Where and When to Measure Forest-Fire Danger

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This article presents the results of a study to determine the place, time, and number of measurements that should be made to obtain dependable ratings of "average-bad" fire conditions without an excessive number of stations or observations. The author concludes that under the conditions prevailing in the Priest River Experimental Forest in northern Idaho a single measurement taken daily at noon at either a valley-bottom or a south-slope station is adequate for the rating of fire danger.

FOREST-fire danger[2] is now measured in every forest region of the United States. Several systems of measuring and evaluating danger have been developed (*3*), all of which are of value in the current supervision of fire suppression and in fire-control planning.

Studies at the Northern Rocky Mountain Forest and Range Experiment Station have aimed consistently to determine (1) what factors affect fire danger, (2) how they may be measured, (3) where they should be measured, (4) when they should be measured, and (5) how to integrate these measurements into a reliable, practical, and readily usable scale. These distinct components of the problem constitute the "what, how, where, and when" of fire danger. The "why" of fire-danger measurement is primarily to indicate the size of the control organization needed to cope with existing fire danger.

Present policies require that preparations be made for controlling all fires that start under "average bad" or easier conditions. This means a fire-control organization capable of suppressing all fires, *except those that might start in the worst fuels under the very worst burning conditions,* and recognizes the importance of the law of diminishing returns in fire-control planning. Hornby (*7*) accepted the fact that beyond a certain point it is more economical to take the loss than it is to bear the cost of preventing that loss. Recently Knorr (*8*) recognized the application of the average-bad principle in selecting the locations of fire-danger stations to be used as a guide in manning for fire control in the longleaf pine type.

It was early recognized that the same principle that governs fire-suppression practices should also govern the place and time of making danger measurements. Fire danger is known to vary greatly from place to place and from time to time at the same place. For example, in the same fuel type the danger is obviously greater on south than on north slopes, at lower than at higher elevations, and during the mid-afternoon than at night. Therefore, if an area is "manned" to cope with the average fire danger of all the aspects, elevations, and hours, the organization should be able to handle with ease all fires on the less-dangerous-than-average north slope, especially those occurring at night; but it would be entirely inadequate to control fires starting on the more-dangerous-than-average south slope, particularly during the critical afternoon period. These important considerations were not adequately taken into account in the statistical analyses of fire-weather station distribution made by Morris (*11*).

In the early stage of measuring fire danger in the Northern Rocky Mountain Region, the availability of men at an established station and convenience in making the measurements were the controlling criteria as to where and when the average-bad should be measured. These are still dominant factors in actual practice. By 1934, however, progress in other phases of evaluating fire danger had shown the need for a better basis. Therefore, very appropriately at that time, a study was started at the Priest River Experimental Forest to find out more precisely how the various fire-danger factors differed in mountainous terrain in order to acquire more complete and basic knowledge of where and when to measure fire danger.

The results of that altitude and aspect study have been given in two previously published

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[2]"Forest-fire danger" is used in its broad sense as defined in the *Glossary of Terms Used in Forest Fire Control,* U. S. Department of Agriculture, Forest Service, 1939, namely, "A general term expressing the sum total of both the constant and variable factors which determine whether fires will start, spread, and do damage, and which determine their difficulty of control."

reports (*5, 6*). This paper will show, in so far as wind and the atmospheric factors affecting fuel-moisture conditions are concerned, how the average-bad fire condition in rugged topography may be evaluated and where and when it can be measured.

Burning Indexes[3] as a Measure of Average-Bad Fire Danger

Fire-weather data were obtained at seven fully exposed stations. One of these, which might be called the valley-bottom control because of its similarity to a danger station at any ranger station, was located in a flat valley bottom at 2,300 feet elevation. The remaining six were established in pairs located on true north and south slopes at elevations of 2,700, 3,800, and 5,500 feet on a ridge rising from east to west. All pairs were within 100 feet elevation of the ridge crest. At each station wind velocity at 7½ feet above the ground and moisture content of duff and half-inch fuel moisture indicator sticks were measured and recorded continuously by an anemo-hygrograph.

The fuel moisture and wind velocity data of each station were integrated by the Northern Rocky Mountain fire danger meter (model 5) into burning indexes on a scale of seven classes. These embrace the entire range of burning conditions, from no spread of fire under Class 1 to spreads of 1,500 to 2,000 acres per hour when the explosive conditions under Class 7 prevail.

Figure 1 shows the altitudinal distribution of the burning indexes on both north and south slopes for 24 hours of the median day[4] in July-August, 1938. The conditions shown are typical or normal for the clear, dry fire weather that is so characteristic of northern Idaho summers. Median values are used, since mean values or arithmetic averages are too much affected by the occasional, unusual stormy weather (*1, 4, 7*) to be typical of the summer climate of this region with its high temperatures, low relative humidity, scanty rainfall, and long periods of drought.

[3]The Committee on Forestry Terminology of the Society of American Foresters has defined burning index as "a relative number denoting the combined evaluation of the inflammability of forest fuels and the rate of spread of fire in such fuels for specific combinations of fuel-moisture content, herbaceous stage, and wind velocity." In some former publications (*5, 6*), burning indexes have been termed "fire-behavior classes."

[4]Median day is the day on which conditions were such that half of the July-August days showed worse fire danger and the other half less fire danger.

Figure 1 may be likened in some respects to a contour map save that its "contours" are lines of equal burning index rather than lines of equal elevation. At 6 a. m., for example, there are "valleys" of low burning indexes at both low and high elevations with "ridges" of high burning index between. These culminate in the highest "peak" around 2 p. m.

The data are readily usable to approximate the burning index at any elevation on north and south slopes between 2,200 and 5,500 feet and at any hour of the day or night. For example, the figures on the vertical line for 6 a. m. in Part A show that the burning index increases from valley bottom up to 3,500 feet and then decreases toward the mountain top, as follows:

Elevation, feet	Burning index, class
2,400	2.6
3,000	3.2+
3,500	3.5
4,000	3.4—
4,500	3.3+
5,000	3.2
5,500	3.1

Similarly, the horizontal line for 3,000 feet elevation on this same slope shows that the burning-index ratings for various hours of the day were as follows:

Hour of day	Burning index, class
10 p. m.	3.8
2 a. m.	3.4
6 a. m.	3.2+
10 a. m.	4.4
2 p. m.	5.2—
6 p. m.	4.6

If average-bad fire danger is concretely defined in terms capable of numerical expression (*10*), the information in Figure 1 obviously can be used to determine when and where to measure "average-bad" with respect to aspect, elevation, and time. The chart clearly shows that at identical hours and elevations, higher burning indexes exist on the southerly aspect (A) than on the northerly aspect (B). Likewise, at all elevations on the southerly aspect the danger is greater between 10 a. m. and 6 p. m., the so-called burning period, than at any other hour of the entire day. These facts lead to one logical conclusion: the measure of the average-bad must be based upon the average of fire-danger conditions as represented by the burning indexes which prevail on the southerly aspect and valley bottom between the hours of 10 a. m. and 6 p. m.

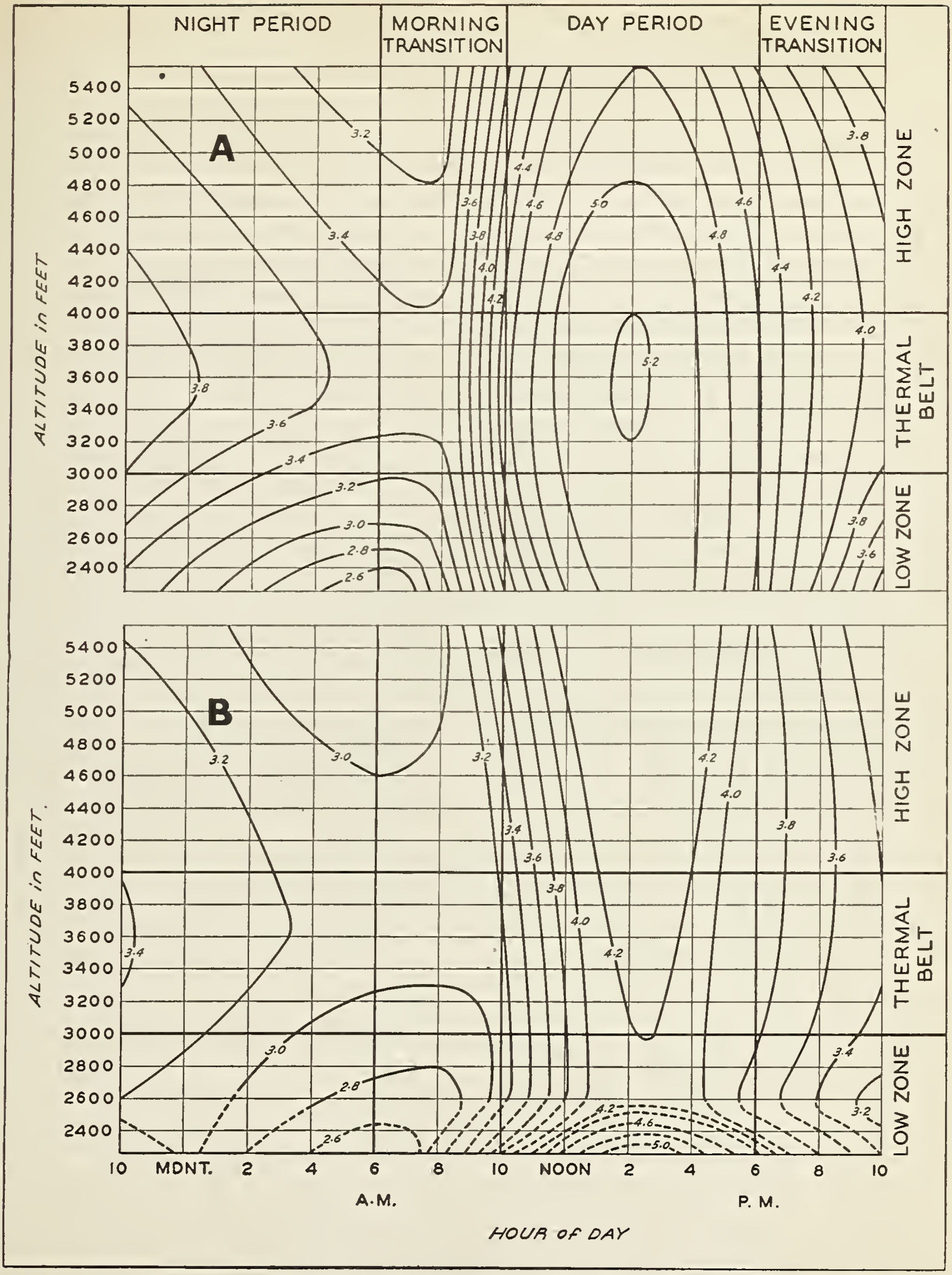

Fig. 1.—Burning-index ratings for different altitudes, different hours of the day and night, and on south (Part A) and north (Part B) slopes for the median day of July-August, 1938, on the Priest River Experimental Forest. The isograms, or "contour lines," are lines of equal burning index.

On the median day of July-August, 1938, the burning index of the average-bad condition was class 4.8. This was obtained as follows: (1) For the two months the average burning index of the critical period (10 a. m. to 6 p. m.) was calculated separately for each of the three south-slope and the one valley-bottom stations. (2) Next, the percentage of all flats and south slopes included in the study area (6,000 acres) which fell within the altitudinal zone best represented by one of each of the four stations was estimated from a topographic map. (3) The average burning index of each station obtained in step 1 was then multiplied by the appropriate percentage from step 2 and the four products were added together. (4) Their sum, class 4.8, was the weighted-average burning index of all south slopes and valley-bottom areas embraced by the study.

Figure 1 (A) shows that on the normal day, between 10 a. m. and 6 p. m., a burning index of class 4.8 occurred twice in the valley bottom and at all elevations on the south slope except at the highest point, where it prevailed only once at 2 p. m. Consequently, the average-bad condition, as defined, could be measured at any place in the valley bottom or on the south slope. In the valley bottom these measurements could be made either at noon or 5 p. m. Measurements at any other hours would give indexes either definitely below or above "average bad" for the area. On the south slope, similar measurements would have to be made at 3,000 and 4,000 feet around 11 a. m. or 5 p. m., and at 5,500 feet around 2 p. m.

Some Practical Considerations

As brought out above, the average-bad can be measured at more than one place, and at different hours of the day in some places. Usually men for this purpose are readily available only at valley-bottom ranger stations or mountain-top lookout points. The valley-bottom and 5,500-foot south-slope stations used in this study were typical of such localities. Measurements of average-bad made at these stations were tested to answer several important practical questions. (1) How accurately do single ratings at an individual station represent the average-bad from day to day; (2) for the stations in question, which of the three ratings approximated average-bad most accurately; and (3) how much can the accuracy of daily ratings be increased by averaging several measurements at an individual station or combining several values from different stations?

Accuracy of Individual Station Ratings

Table 1 shows the accuracy with which the average-bad burning index on any July-August day was approximated by single daily ratings at either the valley-bottom or the mountain-top station. Any of the three single measurements rated average-bad with an accuracy sufficient for practical purposes, but the one at 2 p. m. on the south slope near the lookout station was best. While the practice of measuring only once each day and then only at a lookout station would be readily feasible on most Forest Service ranger districts in July and August, it would not serve during earlier and later months when the lookout stations are often unoccupied.

Relative Accuracy of the Three Sets of Data

As shown in Table 1, the 2 p. m. burning indexes from the south-slope station at 5,500-foot elevation were most accurate. There on 50 per cent of all days tested, the ratings differed from the average-bad burning index by only ±0.1 class or less; on 66 per cent of the days the difference was ±0.24 class or less. However, at the valley-bottom station the readings were almost as reliable. There the noon data varied from the average-bad rating by ±0.15 class or less on half the days, and by ±0.34 class or less on two-thirds of the days. Furthermore than 5 p. m. data at this same station deviated from average-bad by not over ±.20 and ±0.33 classes on half and two-thirds of the days, respectively.

The largest overestimate exceeded the average-bad rating by 1.3 classes and the largest underestimate was 1.0 class too low. These errors might appear to be of practical importance, but they all occurred on days when the average-bad burning index was low. On such days, when fire will not give serious trouble, errors of this amount are not of such significance as when danger is high and success in efficient fire control depends vitally on accurate estimation of conditions.

The maximum overestimate of 1.3 classes occurred, for example, on July 6 when average-bad for the 6,000-acre area as a whole was rated at a burning class of 2.4. At noon on that day, mea-

surements at the valley-bottom station indicated the burning index at class 3.8. However, because of rain which started at 2 p. m. the same day, the 5 p. m. index at this station fell to class 1.6 or 0.9 class below the average-bad. Similarly, the diurnal trend was abnormal on the day immediately following owing to rapid drying of unusually wet fuels. Only on days which were affected by recent rain did errors exceeding ±0.5 class occur. No error exceeding that amount occurred on any day unaffected by rain which rated class 3.6 (moderately bad) or more. In fact, on the moderately dangerous days the ratings were generally accurate within ±0.3 class and less.

Increasing the Accuracy of Ratings

While such accuracy is reasonably good, analysis shows that averages of two or more measurements from a single station or from separate stations give greater accuracy than any individual measurement. Three different combinations of two daily estimates and one additional combination of all daily measurements were tested.

As is evident from Table 2, averages of three daily measurements, two in the valley bottom and one on the mountain top, approximated average-bad with remarkable dependability. The median and standard errors of such an estimate were reduced to the inconsequentially low points of about one-tenth of a class. Even its largest single error, an overestimate of 0.4 class, would not be of serious importance to a protective organization. Two measurements in the valley bottom and one on the mountain top each day therefore can be used, if justifiable on other bases, to give maximum accuracy.

Discussion

The above analyses indicate that theoretically the average-bad burning index can be best approximated from combinations of three daily measurements at two stations. From the practical point of view, however, can any fire-control organization really make use of ratings as refined as this? To state the question from another angle: Will the additional cost of making more than one daily measurement be justified by the financial benefits derived from the most accurate but also the most costly estimate based on three measurements?

Such questions must be answered negatively for the Northern Rocky Mountain Region when consideration is given to our knowledge of fire behavior, the uniformity of danger from day to day, and the degree of refinement employed in present-day fire-control work. Analysis indicates that on the two-thirds of the days that a fire-control organization would have been most vitally concerned with the fluctuating danger,

Table 1.—Accuracy with Which the Average-Bad Burning Index was Approximated by Single, Daily Measurements at Different Stations, July-August, 1938

Station and hour	Median error of estimate[1]	Standard error of estimate	Greatest over-estimate	Greatest under-estimate
	Class	*Class*	*Class*	*Class*
Valley bottom, 2,300 feet				
12:00 m.	±0.15	±0.34	+1.3	—0.9
5:00 p.m.	±0.20	±0.33	+0.9	—1.0
South slope, 5,500 feet				
2:00 p.m.	±0.10	±0.24	+0.6	—0.6

[1]The median difference between the measured and the estimated average-bad burning index.

Table 2.—Accuracy with Which the Average-Bad Burning Index was Approximated by Combining the Daily Measurements of Two and Three Stations, July-August, 1938

Station and hours	Median error of estimate	Standard error of estimate	Greatest over-estimate	Greatest under-estimate
	Class	*Class*	*Class*	*Class*
Valley bottom at 12 m. and 5 p.m.	±0.10	±0.19	+0.8	—0.4
Valley bottom at 12 m. and south slope, 5,500 feet, at 2 p.m.	±0.08	±0.18	+1.0	—0.4
Valley bottom at 5 p.m. and south slope, 5,500 feet, at 2 p.m.	±0.09	±0.16	+0.3	—0.7
Valley bottom at 12 m. and 5 p.m., and south slope, 5,500 feet, at 2 p.m.	±0.06	±0.11	+0.4	—0.2

single measurements estimated the average-bad from only ±0.05 to ±0.18 class less accurately than did two observations, and only ±0.13 to ±0.23 class less precisely than the median of three measurements. No fire control force in this region is at present so flexible that it can be varied for a change of only 0.23 class in fire danger.

Moreover, the variations in fire behavior within the different burning-index classes have not yet been determined to a degree that economically justifies increasing or decreasing a fire-control force to meet a change of ±0.34 class, the largest standard error for estimates based upon single daily measurements. Until fire control action can be refined to the point of actually making changes in the control forces with variations of one-third class of fire danger, one daily measurement is therefore recommended as adequate on any unit similar to the one studied.

These tests are strictly applicable, of course, only to the sampling of average-bad as here defined and computed. There is no reason, however, if some other index were wanted, why it could not be approximated by similar methods and with similar accuracy. Average-bad danger on forest areas larger than 6,000 acres could not be determined so accurately perhaps; but an accuracy within practical limitations should be obtainable during settled weather on an area many times larger than 6,000 acres providing it is climatically uniform.

Burning-index measurements, in addition to their value for rating danger on an area as a whole, also can be used by fire dispatchers to estimate burning conditions at any spot on their unit where a new fire occurs. The manner in which this may be done can be illustrated by using the values in Figure 1 to show the relationship between the danger actually measured and the danger estimated to be existing "at the fire."

Let it be assumed that two fires are reported on a day when the noon burning index of the valley-bottom station was measured and found to be class 5.2, or 0.3 class above the index shown by Figure 1 for such a station and hour. Further, assume the first fire as occurring at 3 p. m. on a south slope at 3,800 feet and the second at 8 p. m. on a north slope at 2,600 feet. According to Figure 1 (A) the aspect-elevation combination for the first fire gives a rating of about class 5.1. But this chart shows only what can be expected if the valley-bottom condition was rated as 4.8 at noon. As the valley bottom rating was actually 5.2 at noon on the day of this fire, the difference, or 0.3 class, must be added to the 5.1 shown for the fire location. The estimated burning index at the site of the first fire was therefore 5.1 plus 0.3 or class 5.4.

Similarly the danger at the site of the second fire as estimated from Figure 1 and corrected by the noon measurement was class 4.0 (class 5.2 of valley-bottom station at noon minus class 1.2, the normal difference between ratings of the valley-bottom station at noon and of a spot on the north slope at 2,600 feet elevation at 8 p. m.). The local ranger thereby is able to judge and to report probable fire behavior at these two fires far more dependably and specifically than would otherwise be possible. The action he takes for a 5.1 condition obviously will be both stronger and faster than for the class 4.0, even though the latter represents a spot at lower elevation, hence with more area above it and exposed to burning. While these are conditions and actions readily apparent to the experienced forest officer, they are not so obvious and are often overlooked by the new man to whom all fires may look equally sinister.

The several possibilities of making daily measurements were analyzed also to determine which would be the best basis for dispatchers' estimates of this kind. Each combination of station measurements was used in turn with values shown in Figure 1 to estimate burning indexes at three different sites and widely different hours. Furthermore, additional charts were constructed similar to Figure 1 but with each representing a certain limited range of danger at noon at the valley-bottom station. In using Figure 1 for this test, the estimates were confined to those days that rated 4.3 to 5.3 at the valley-bottom station. Other charts should be used for lower and higher dangers. This limited the number of estimates in each group to 30. Table 3 shows the dependability found for any one of three different measurements when used as a basis for estimating conditions on any July-August day at three other spots within the area.

In seven of the nine cases the estimated burning indexes differed from the actual by only ±0.2 class or less, on half of all the days tested. In the other cases the differences were even smaller, from ±0.1 to ±0.15 class or less. This uniformity of the median errors of estimate shows that on at least 50 per cent of the July-

TABLE 3.—ACCURACY WITH WHICH THE BURNING INDEX AT THREE DIFFERENT PLACES AND HOURS WAS ESTIMATED FROM MEASUREMENTS TAKEN AT THE VALLEY-BOTTOM STATION AT NOON AND AT 5 P.M., AND AT THE SOUTH-SLOPE STATION 5,500 FEET ELEVATION AT 2 P.M.

Situation and hour of measurement	Situation and hour of estimate	Median error of estimate	Standard error of estimate	Greatest over-estimate	Greatest under-estimate
Valley bottom, noon	South, 3,800 feet, 2 p.m.	±0.15	±0.27	+0.7	—0.4
	North, 2,700 feet, 8 p.m.	±0.2	±0.25	+0.7	—0.3
	South, 5,500 feet, 10 a.m.	±0.2	±0.40	+1.3	—0.7
Valley bottom, 5 p.m.	South, 3,800 feet, 2 p.m.	±0.2	±0.41	+0.7	—0.7
	North, 2,700 feet, 8 p.m.	±0.1	±0.22	+0.6	—0.5
	South, 5,500 feet, 10 a.m.	±0.2	±0.39	+0.8	—0.9
South slope, 5,500 feet, 2 p.m.	South, 3,800 feet, 2 p.m.	±0.2	±0.22	+0.4	—0.6
	North, 2,700 feet, 8 p.m.	±0.2	±0.40	+0.6	—1.3
	South, 5,500 feet, 10 a.m.	±0.2	±0.35	+1.0	—0.9

August days concerned, the distribution of burning indexes was so similar to that shown by Figure 1 that it mattered little where or when the measurements were made. For example, on half the days the burning indexes at 2 p. m. on the south slope at 3,800 feet elevation were estimated just as accurately from measurements made 21 hours earlier and 1,500 feet below (valley station at 5 p. m.) as from observations taken at the same time and 1,700 feet higher (south-slope station 5,500 feet at 2 p. m.) In each case the median error was the same, ±0.2 class.

The standard errors in Table 3 show, however, that on days when the distribution of fire danger was not so typical, greater accuracy was obtained when the measured and estimated burning indexes were made near each other with respect to both place and time. Thus, the standard error for estimates of 2 p. m. burning indexes at 3,800 feet on the south slope was only ±0.22 class when based upon measurements made at the 5,500-foot south-slope station at 2 p. m. It was ±0.41 class when using 5 p. m. measurements of the valley-bottom station.

Large overestimates and underestimates in excess of ±0.5 class occurred occasionally at all of the stations tested (Table 3). Errors of that magnitude are probably less important in the present instance than they would be in rating general fire danger. In actual dispatching they would be largely avoided. No dispatcher, for example, would accept or use without modification an estimate of the burning index following a rain which was based upon measurements that were taken before that rain started. Yet four of the largest overestimates in Table 3 were caused by exactly such a combination of conditions. Similarly, when the typical topographic distribution of fire danger is disturbed by uneven distribution of rain, by unusual changes in wind velocity and direction, or by cloudiness, then the estimates of burning index should and must be modified by common-sense allowances based upon experienced judgment. Good dispatching will always demand the exercise of sound judgment. This can be guided, but never replaced, by mechanical methods of estimating.

For use in dispatching, burning indexes should therefore be measured as near as practical to bad fire zones and preferably just prior to the time of day when fires usually occur. In this connection, noon measurements should be more valuable than those made at 2 p. m.; the latter in turn should have greater value than 5 p. m. data. Both for use by the fire dispatcher and in over-all fire-danger rating, measurements should not be made during those before-noon hours when the burning index is changing rapidly, i.e., in valley bottoms from 7 through 11 a. m., and at mid-elevations on south slopes from 8 through 10 a. m. Measurements made at such times are not so reliably indicative of what conditions will be elsewhere on the area as are measurements made after the burning index has come to its daily comparative equilibrium.

SUMMARY

Fire-danger ratings are necessary to sound fire-control planning. Among other uses, they furnish a very practical index of the presuppression manpower needed on an area. Danger measurements made at one spot and used to rate the fire danger of the immediately surrounding area must be representative of the more dangerous portions of the area and of the more critical hours of the day, but not the most dangerous exposures at the very peak of the day. This average-bad condition can be sampled and expressed numerically through burning indexes obtained by integrating measurements of fuel

moisture and wind velocity. For the area included within the 6,000-acre Priest River Experimental Forest, it was found that these measurements could be made either in the valley bottom at noon or 5 p. m., and on south slopes, depending upon elevation, at 11 a. m., 2 p. m., or 5 p. m.

Single daily measurements made at a valley-bottom station at noon or 5 p. m., and at a 5,500-foot south-slope station at 2 p. m., represented the average-bad burning indexes for the area as a whole with an accuracy well within the limits of the practical application of fire-danger ratings. A combination of two daily measurements gave more representative burning-index values than did single observations, while three daily measurements improved the accuracy of average-bad ratings still further. Few, if any, fire-control organizations are, however, sufficiently flexible to use effectively burning indexes more precise than those obtained from single daily measurements. Nor is present-day knowledge of fire behavior so complete that minute differences in estimated fire danger have practical implications. Hence, there is no economic justification for financing additional measurements in order to obtain relatively meager further refinement.

For dispatching purposes it matters little on normal or average July-August days in the Northern Rocky Mountain Region where or when the burning index is measured. Each of three sets of data taken at different sites and hours of the day provided almost equally precise estimates of the burning index at other places and hours. On less typical days such as when rain occurred, however, better estimates were obtained when measured and estimated burning indexes were made near each other with respect to both place and time. Under these conditions the need of the fire dispatcher would be best served when measurements are made close to high-danger areas and near the beginning of the daily critical period. From the dispatcher's point of view, the noon measurement is the best of the three time periods tested and the 2 p. m. measurement is next best.

Literature Cited

1. Gisborne, H. T. 1935. When a normal is not a normal. Amer. Met. Soc. Bul. 16: 171-175.
2. ————. 1939. Hornby's principles of fire-control planning. Jour. Forestry 37: 292-296.
3. ————. 1939. Forest pyrology. Sci. Monthly 49(7): 21-30, illus.
4. Hayes, G. Lloyd. 1935. Don't let a "normal" deceive you. U. S. Forest Serv. Bul. 19:4.
5. ————. 1941. Influence of altitude and aspect on daily variations in factors of forest-fire danger. U. S. Dept. Agric. Cir. 591. 38 pp., illus.
6. ————. 1942. Differences in fire danger with altitude, aspect, and time of day. Jour. Forestry 40:318-323, illus.
7. Hornby, L. G. 1936. Fire control planning in the Northern Rocky Mountain region. North. Rocky Mountain Forest and Range Expt. Sta. (Multi.).
8. Knorr, Phillip. 1942. Variations in fire-danger factors on a ranger district in the longleaf pine region. Jour. Forestry 40: 689-692.
9. Mindling, George W. 1940. Do climatological normals serve adequately as normals? Amer. Met. Soc. Bul. 21:3-6.
10. Morris, William G. 1939. What is "average bad?" Fire Control Notes 3(3):25-26.
11. ————. 1940. Statistical analysis of forest-fire weather station distribution. Jour. Forestry 38:318-321.